

# Evaluation of the Change in Physical Features of Two Over-Wide Channel Stream Relocation Projects

## **A Thesis**

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## TABLE OF CONTENTS

<b>TABLE OF FIGURES</b>	<b>IV</b>
<b>TABLE OF PHOTOGRAPHS</b>	<b>IV</b>
<b>ABSTRACT</b>	<b>1</b>
<b>INTRODUCTION</b>	<b>1</b>
<b>OBJECTIVES</b>	<b>3</b>
<b>THEORY</b>	<b>3</b>
<b>METHODS</b>	<b>6</b>
Geomorphological Surveys	6
Turbidity	7
Photographs	7
<b>PROJECT SITES</b>	<b>8</b>
Big Walnut Tributary	8
Clover Groff Run	9
<b>RESULTS AND DISCUSSION</b>	<b>10</b>
Geomorphological Surveys	10
<i>Big Walnut Tributary</i>	10
<i>Clover Groff Run</i>	13
Turbidity	15
<i>Big Walnut Tributary</i>	15
<i>Clover Groff Run</i>	17
Photographs	17
<i>Big Walnut Tributary</i>	17
<i>Clover Groff Run</i>	18
<b>CONCLUSION</b>	<b>18</b>
<b>FUTURE STUDIES</b>	<b>18</b>

<b>REFERENCES</b>	<b>20</b>
<b>APPENDIX A: PHOTOGRAPHS</b>	<b>22</b>

## TABLE OF FIGURES

Figure 1 - Typical two-stage channel.....	4
Figure 2 – Over-wide channel.....	4
Figure 3 - Upper Scioto River Regional Curve .....	5
Figure 4 – Map of Big Walnut study site .....	8
Figure 5 – Map of Clover Groff study site .....	9
Figure 6 - Big Walnut profile comparison.....	11
Figure 7 - Big Walnut cross-section 1 .....	12
Figure 8 - Big Walnut cross-section 2.....	12
Figure 9 - Big Walnut cross-section 4.....	12
Figure 10 - Big Walnut cross-section 3 .....	13
Figure 11 - Clover Groff profile comparison.....	14
Figure 12 - Clover Groff pattern comparison .....	15
Figure 13 - Turbidity and stage data at upstream end of Big Walnut study site.....	16
Figure 14 - Turbidity comparison between upstream and downstream for Big Walnut...	17

## TABLE OF PHOTOGRAPHS

Photo 1 - Big Walnut 09/01/2005 .....	24
Photo 2 - Big Walnut 11/16/2005 .....	24
Photo 3 - Big Walnut 06/27/2006 .....	24
Photo 4 - Big Walnut 08/28/2006 .....	24
Photo 5 - Big Walnut 01/03/2007 .....	24
Photo 6 - Big Walnut 05/17/2007 .....	24
Photo 7 - Clover Groff September 2005.....	26
Photo 8 - Clover Groff November 2006.....	26
Photo 9 - Clover Groff May 2007 .....	26

## **Abstract**

The over-wide channel design is a recent, innovative, channel modification design. In this design, the channel is constructed as a wide, flat trapezoid at the channel bed elevation. The theory behind the design states that over time, floodplain benches will form, creating a stable two-staged geometry with a functional floodplain. This design could function as a stormwater management practice designed to provide flood storage and channel protection. This study begins the process of gathering data to create a database to (1) evaluate whether following construction the evolution of over-wide channels is consistent with theory; and (2) if the channel does evolve according to theory, to initiate the work necessary to determine how quickly it will take for an over-wide channel to evolve into a two-stage system. The parameters examined in this paper are geomorphology, turbidity, and sequential photographs. This study examined two study sites; Clover Groff Run and a tributary to Big Walnut Creek. While little change was observed at the Clover Groff Run site, the formation of a small inset channel and attached floodplain system was observed at the Big Walnut Creek study site. This channel was 8 feet wide and 0.75 feet; within the predicted range of the design. While aggradation and down-cutting were both observed at the study site, the measured inset channel was formed predominantly by down-cutting. Future studies are needed to definitively quantify the evolution of over-wide channels.

## **Introduction**

U.S. EPA, by passing the Clean Water Act, has recognized the growing concern for storm water management. Pavement, roof tops, and other impervious surfaces within a watershed convey rainwater more quickly than the natural soils and vegetation they have replaced. These impervious surfaces also restrict the infiltration of rainwater into the groundwater supply, increasing the volume of runoff compared to natural soils (Storm Water Center, 2006).

As more land becomes developed and impervious, the amount of runoff increases and is conveyed to streams and rivers more quickly and with a higher velocity. These increases cause downstream flooding and failing stream morphology (Storm Water Center, 2006).

The three main objectives to stormwater management are water quality management, flood control, and stream protection. In Ohio, the minimum stormwater management requirements only consider the first objective of water quality; which is regulated by the standard of water quality volume (WQv) (Stormwater Authority, 2007). The WQv is calculated as:

$$WQv \text{ (ac-ft)} = C * 0.75 * A / 12$$

Where A is the area draining into the stormwater management practice in acres and C is the runoff coefficient; these coefficients range from 0.2 for open space and recreational areas to 0.8 for industrial and commercial areas. The 0.75 represents the first 0.75 inches of rainwater during a storm event. (ODNR DSWC, 2006). This volume is considered the

“first flush” and contains the largest volume of pollutants from surface runoff. This volume must be retained for 24-48 hours; allowing for sediments and pollutants to settle out (ODNR DSWC, 2006).

The requirements for WQv are most easily met by retention and detention ponds and this is how it has been traditionally handled. The ponds are sized with a minimum storage volume of the WQv and the outlets are sized to drain that volume over 24-48 hours (ODNR DSWC, 2006). This often leads to small outlets and large volumes.

Ohio does not require stormwater management practices to meet the second objective of providing flood control; however, local governments may require developers to implement a flood management strategy. The Ohio Department of Natural Resources Division of Soil and Water Conservation (ODNR DSWC) provides the Critical Storm Method (ODNR DSWC, 2007). The Critical Storm Method reduces the post-urbanization peak flows for the critical storm and all of the more frequent storms to that of the pre-urbanization one year 24 hour storm event. All larger storms’ peak flows are to be reduced to their pre-urbanization peak flows. The critical storm is determined by the percent of runoff increase (ODNR DSWC, 2007). This peak flow reduction is often handled by the stormwater ponds required for WQv. The size of these ponds is increased, allowing for the retention of the increased peak flows (Ward and Trimble, 2004).

The third objective of stream protection and the maintaining of self-sustaining stream systems is generally not required (Ward and Trimble, 2004). “The most common strategy to provide channel protection is to hold postdevelopment peak discharge rates to 2-year predevelopment levels. However, this strategy often releases flows above the effective discharge for a longer period of time than occurred prior to development and theoretically results in greater transport of suspended sediment and bedload” (Ward and Trimble, 2004). Mecklenburg and Ward (2002) suggest the sizing of stormwater ponds to maintain the pre-development effective discharge, the streamflow that transports the most sediment over the long term (Ward and Trimble, 2004), and sediment transport rather than focusing on reducing peak flows.

Another approach to maintaining stable stream systems is to attach or maintain an active floodplain (Ward, in press; Rosgen, 1997) and to provide adequate space for the channel system to self-adjust its dimensions, pattern, and profile (Ward and Trimble, 2004). Based on a study of agricultural ditches in Ohio, Powell et al. (2006) recommend that a floodplain ratio (flooded width divided by the bankfull channel width) of 3-5 will enhance stability and provide some water quality and ecological benefits but will not usually establish the meander pattern suggested by theory. Ward et al. (2007) suggest a floodplain ratio of at least 5 to 10 times the channel width is needed to establish or maintain a self-sustaining stream system. In Ohio, many channel systems have been straightened and deepened, are agricultural ditches, have become incised, or have an inadequate floodplains. Also, high quality fully functional natural streams located on will often need more space and larger floodplains if they are located in watersheds where there is urban development. Therefore, it is thought that a more beneficial stormwater management practice than using retention/detention ponds as the primary practice would be to provide receiving channel larger active floodplains and more space to self-adjust. The increased size of the active floodplains would provide a portion of the WQv storage, would be size to ensure that post-development discharges do not exceed pre-development

discharges, and most importantly would reduce the potential for increased scour in the channel system. Criteria on how to size these floodplains and methods to quantify their benefits and not yet been determined and are the main reason for the work that was initiated and is reported in this thesis.

In Ohio, in order to use an innovative stormwater management practice, it must be proven that the practice fulfills all of the current legal requirements (Ohio EPA, verbal communication with Andy Ward). This translates into proving the practice provides the required WQv storage and detention time.

## **Objectives**

There have been 12+ sites around Ohio utilizing the over-wide channel design for stream channel modification. A majority of these sites utilized the design when relocating an existing stream for land development purposes and none of the sites constructed the over-wide channel as an alternative stormwater management practice.

This study is creating the starting point for the evaluation of how over-wide channels evolve after construction and for documenting their benefits. It is the author's hope that this information can be used to begin a research database providing evidence of the stormwater management benefits of the over-wide channel design which can then be used to create regulatory and engineering standards.

This study examines the geomorphology, turbidity, and a sequence of photographs at two study sites in Franklin County, Ohio. The specific objectives of the study are to: (1) evaluate whether following construction the evolution of over-wide channels is consistent with theory; and (2) if the channel does evolve according to theory, to initiate the work necessary to determine how quickly it will take for an over-wide channel to evolve into a two-stage system.

## **Theory**

Engineers at the Ohio Department of Natural Resources and the Ohio State University observed that drainage ditches that were constructed overly wide most often had small floodplain benches form inside them through deposition (Jayakaran, 2006). These depositional benches created a stable stream system, with a small inset channel and floodplain bars, within a larger deeper channel. A stream with this type of cross-sectional geometry is referred to as a two-stage channel. A typical two-stage channel is shown in Figure 1.

From field observation, the engineers developed knowledge on the performance and design of two-stage channel systems (Powell et al, 2006). Like a stable stream with a connected floodplain, a two-stage channel can dissipate the energy of high flows thus providing a more stable stream morphology and ecology than a traditional drainage ditch or an entrenched stream. The two-stage channel technique has been accepted by Ohio EPA as a technique eligible for funding from the Nonpoint Source Program Grant (Ohio EPA, 2007).

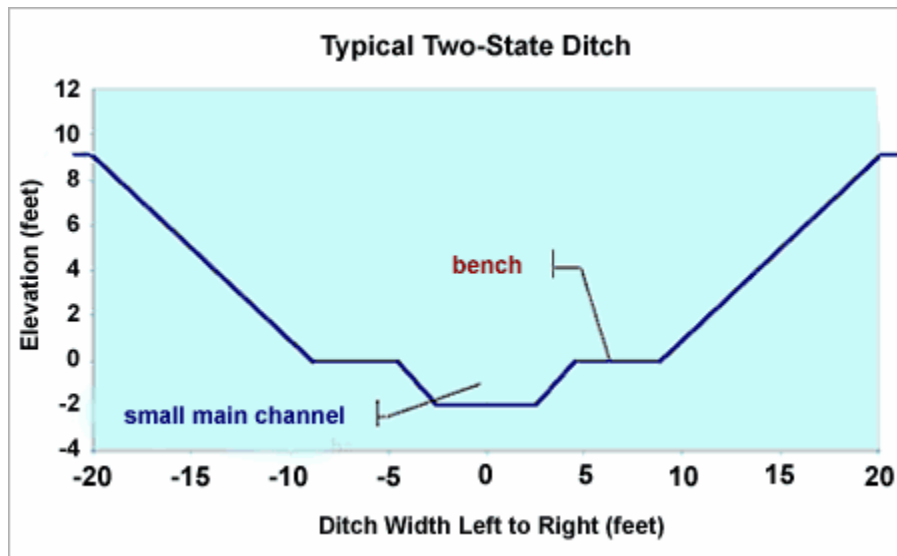


Figure 1 - Typical two-stage channel

The over-wide channel design is a variation of the two-stage ditch design. With this approach, excavation is down to the channel bed level across the entire floodplain width, as opposed to constructing the “two stages” of the two-stage ditch. The stream is then free to form a stable channel by depositing sediment in the vegetation, forming floodplain bars. Figure 2 shows a typical cross section of an over-wide channel. Unintentional demonstration of the process is common, principally where drainage ditches have been constructed with adequate width (Rhodes and Herricks, 1996; Landwehr et al., 2003).

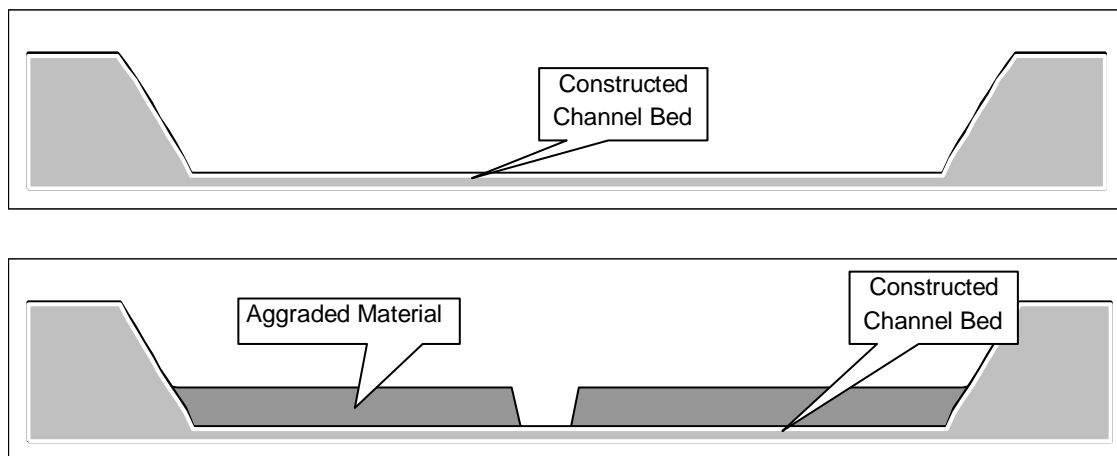


Figure 2 - Over-wide channel

It is theorized that as compared to a constructed two-stage channel, that often have much of the floodplain constructed of dense parent material, the floodplains of the over-wide channel will allow for higher biological, hydraulic, and chemical activity due to the rich alluvial soils that make up the floodplains. If there is an insufficient sediment



supply, instead of aggrading to form a channel, the over-wide channel will become a linear wetland, which would still allow for high biological, hydraulic, and chemical activity. The rate of floodplain formation is dependent upon the storm events and the sediment load the channel experiences. Unfortunately, there

The over-wide channel design is sized in order to promote the development and continuation of a stable, self-sustaining stream system. First, the expected channel width and depth are sized. If the original stream has an apparent stable geometry, this geometry can be measured and then used to size the over-wide channel. However, in many urban environments, the existing channels have been modified and are unstable. In this case, a regional curve must be used. A regional curve is a mathematical relationship predicting the channel geometry based on the drainage area. The curve is created by taking field measurements throughout the watershed at stable sites and then measuring the drainage areas from topographic maps. Regional curves have been created from large scales, such as that of the eastern United States, to watershed specific curves. These curves often have an associated error of  $\pm 50\%$ . The regional curve for the Upper Scioto River watershed is shown in Figure 3.

Once the channel has been sized, the floodplain must be sized. It is recommended to use a minimum floodplain width of 3 times the sized channel width, while larger widths of 5 to 10 times the channel width are encouraged (Ward, in press). Often the floodplain width is limited by the practical constraint of available land.

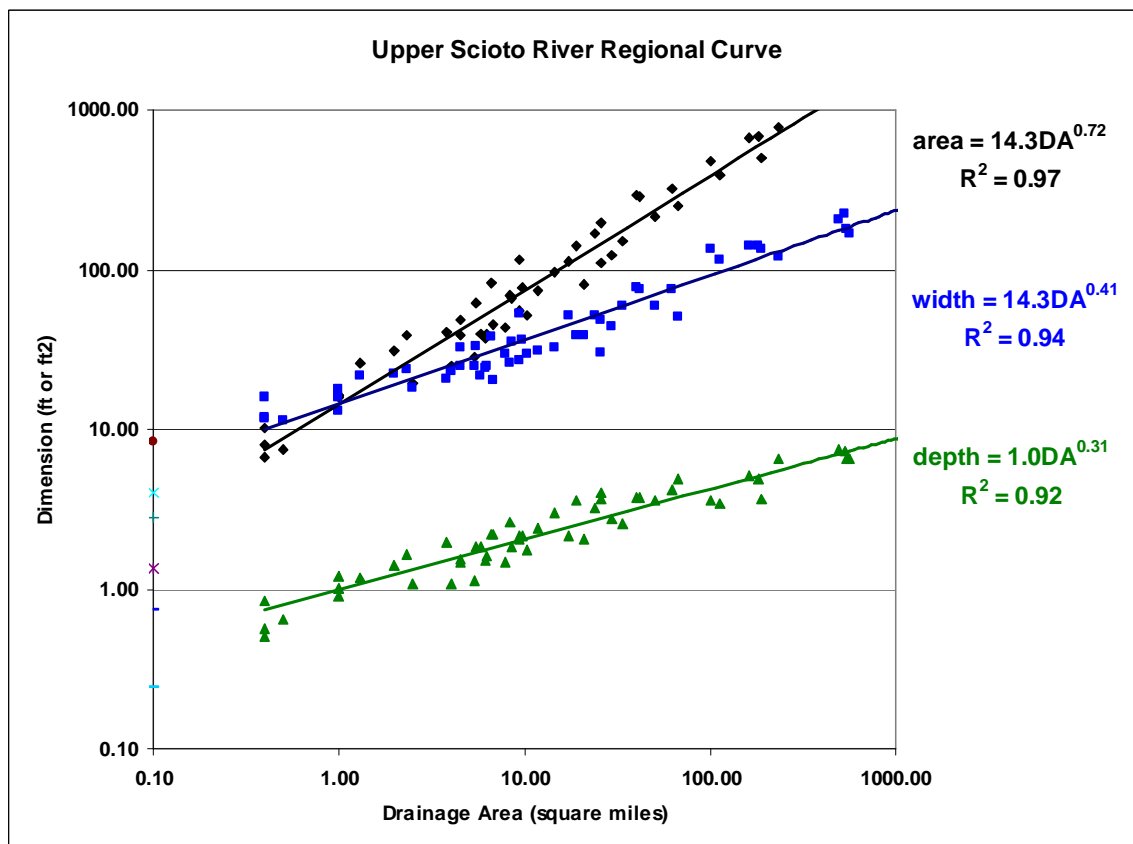


Figure 3 - Upper Scioto River Regional Curve

From these dimensions, a theoretical two-stage channel has been sized within a larger ditch. This geometry is shown in Figure 1. This is the geometry expected to develop over time. To obtain the constructed over-wide geometry, the ditch side slopes are extended to the channel bed elevation. This creates a wide, trapezoidal geometry shown in Figure 2. The width of this channel is smaller than the desired floodplain width, as it is expected that the floodplain will build up and eventually obtain the desired width.

## Methods

Three methods were used to monitor the physical changes occurring at both project sites. The first monitoring method is a geomorphological survey. This survey measures channel slope, the meandering pattern, and channel cross-sections. From the cross-sections, whether the development of floodplains and a smaller inset channel or bankfull channel occurs can be observed.

The second monitoring method is the measurement of turbidity in upstream and downstream samples. Christensen et al. (2005) determined that there is a high correlation between total suspended solids (TSS) and turbidity. By comparing the turbidity from upstream and downstream samples, the relative quantity of TSS can be inferred; suggesting whether the over-wide channel traps or generates suspended sediments.

The third monitoring method is the use of sequential photographs of the over-wide channel. These photos demonstrate a qualitative change in physical features that can not be conveyed from the measurements. All measurements and photographs were taken by the author and an accompanied team of students and engineers from The Ohio State University Department of Food, Agricultural, and Biological Engineering and the Ohio Department of Natural Resources Division of Soil and Water Conservation.

## Geomorphological Surveys

The geomorphological surveys were performed using a laser level, measuring rod, receiver, measuring tape, and compass. The laser level is positioned above the highest elevation and the measuring rod and receiver measure the difference in ground elevation and the elevation of the laser. This data is then tied into a known benchmark, allowing the repeated surveys to be compared.

The survey is performed by three researchers. The first researcher carries the measuring rod and the front end of the measuring tape, while the second researcher carries the measuring tape reel and a compass. The first surveyor moves from point to point measuring bed elevation and the second surveyor measures the distance between the points with the measuring tape and the angle between the points using the compass. All of this data is recorded by the third researcher and then entered into *The REFERENCE REACH Spreadsheet version 4.01 L* ([www.ohiodnr.com](http://www.ohiodnr.com)).

The first survey of the Big Walnut tributary was performed on March 17, 2006 and the second survey was performed on July 26, 2006. During the March survey, the measured cross-sections were marked with wooden stakes and rebar to reproduce them

during the July survey. The surveys of Clover Groff Run were taken on July 6, 2006 and September 19, 2006.

The measured profiles and cross-sections for the two survey dates were then overlaid on each other to determine if there was a change in bed elevation and whether that change was due to aggradation or down-cutting. In order to make the profiles comparable, the channel length was measured in the center of the over-wide channel while the profile bed elevation measured at the deepest point of the preferential flow path.

There is some inherent error in the method used to survey the sites. If the bed material is unstable, the measuring rod and researcher may sink into the ground. This sinking may produce a lower bed elevation measurement than actually exists. Also, the researchers recorded data points along the thalweg or preferential flow path. Depending on the weather, the apparent thalweg in the over-wide systems may change, causing discrepancies in the repeated surveys.

## **Turbidity**

Due to limited resources and equipment, the only water quality parameter studied during this project was turbidity. Christensen et al. (2005) found a high correlation ( $R^2$  ranging from 0.879 to 0.911) between total suspended solids (TSS) and turbidity.

Grab samples were taken from the tributary to Big Walnut Creek during a storm event on August 28, 2006. This sampling was performed by two researchers. The time and water depth were recorded when the upstream sample was taken. The samples were taken in one liter plastic bottles. The upstream researcher released floating particles in a cluster in the sample of water he surveyed; thus allowing the downstream researcher to sample the same water and compare the two samples. The samples were taken back to the lab and analyzed by a turbidimeter (Model 2008, LaMotte, Chestertown, Maryland). Each sample was analyzed three times and the sample bottles were shaken prior to each sampling in order to re-suspend any settled particles. The turbidimeter measures the amount of light scattered 90 degrees by the suspension and displays this quantity in Nephelometric Turbidity Units (NTU). The available meter ranged from 0 to 199.9 NTU. The upstream samples were then compared to the downstream samples to see if and how the turbidity changed.

## **Photographs**

Prior to and since construction, photographs have been taken periodically of both project sites. Photos taken at different times were compared to identify how each study site changed visually. Photographs were taken more frequently than the surveys since only one person is needed to take photographs. These photographs were also compared to photographs taken during a preliminary study prior to this project.

## Project Sites

During the course of this project, two over-wide channel sites in Franklin County were studied. Both projects began construction during late spring 2005 and construction was completed for both sites during September 2005.

### Big Walnut Tributary

The first project site is located on an unnamed tributary to Big Walnut Creek in Franklin County, Ohio. The site is located at the south-east corner of the intersection of Morse Road and Hamilton Road. The drainage area is 0.5 mi<sup>2</sup>. The watershed is currently under going rapid urbanization. The project site is shown in Figure 4. Both the old channel and the existing channel path are shown. Developers relocated this reach in order to create a shopping center where the tributary once was. The open field along Hamilton Road is now fully developed into a shopping center. The tributary enters the project site through a culvert. The study site ends where the over-wide section rejoins the old channel. The over-wide channel was constructed with a width of approximately 35 ft and an average slope of 0.34%. From the Upper Scioto River regional curve, the expected bankfull width ranges between 5.4 and 16.1 feet and the expected bankfull depth ranges between 0.4 and 1.2 ft. This creates a floodplain ratio between 2.2 and 6.5.



Figure 4 - Map of Big Walnut study site

## Clover Groff Run

The second project site is located on Clover Groff Run in Franklin County, Ohio. The project site is located approximately 1500 ft north of the intersection of Scioto and Darby Creek Road and Alton and Darby Creek Road and just west of Parkmeadow Lane. The study reach is shown in Figure 5. The drainage area is 2.6 mi<sup>2</sup>. When this reach of Clover Groff Run was relocated, the watershed was predominantly agricultural. However, that cropland is currently and quickly being converted into suburban housing. According to the developer, they chose to relocate Clover Groff Run for stormwater credit and improving the view for homeowners. The developer chose to leave the old channel intact; allowing flow in both the old channel and the over-wide channel. The study reach begins where Clover Groff Run first splits upstream into the old channel and the over-wide channel and ends when the over-wide channel ends. This is shown in Figure 5. The over-wide channel was constructed with an average width of 95 ft and an average slope of 0.08%. From the Upper Scioto River regional curve, the expected channel width ranges between 10.6 and 31.7 ft and the expected depth ranges between 0.7 and 2.0 ft. This would create a floodplain ratio ranging between 3.0 and 9.0.



Figure 5 - Map of Clover Groff Run study site

## Results and Discussion

### Geomorphological Surveys

#### *Big Walnut Tributary*

The comparison of the two measured channel profiles is shown in Figure 6. Figure 6 shows that the tributary to Big Walnut Creek has down-cut along the majority of the project reach from March 17, 2006 to July 26, 2006. The down-cutting is observed from distance 63 ft to 355 ft and then again from 469 ft to the end of the study site (all distances are measured from the upstream culvert). Aggradation was observed between distances 355 ft to 469 ft. This section during the March survey is best described as a long shallow pool with a negative slope from distance 347 ft to 504 ft. This would create a condition capable of trapping the material scoured out upstream.

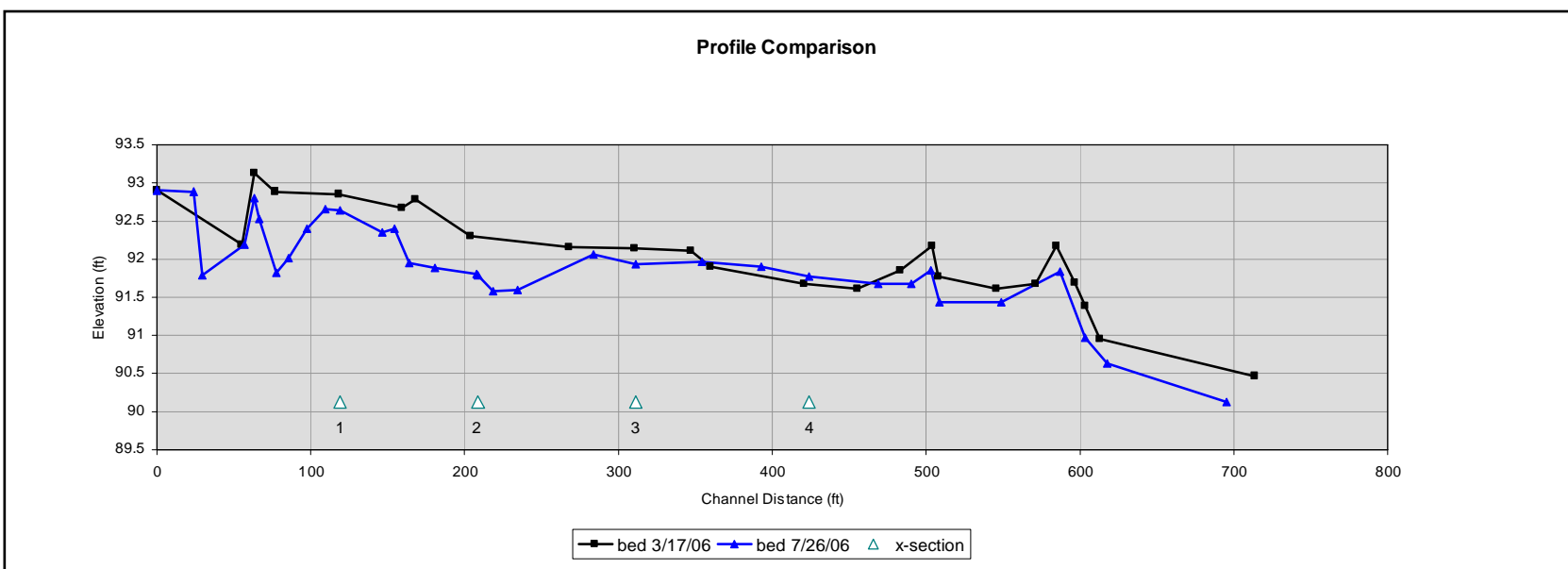
From examining the comparisons of the cross-sections, more details about the physical changes can be seen. The first two cross-sections were both performed in sections where the profile comparison shows down-cutting and, in fact, down-cutting is observed in both cross-section 1 and cross-section 2. Cross-section 1 is shown in Figure 7 and cross-section 2 shown in Figure 8. In cross-section 1, down-cutting of approximately 0.25 ft is observed across roughly the middle 12 ft of the over-wide channel. In cross-section 2 a more defined channel is observed. Figure 8 shows that a channel approximately 8 ft wide and 0.75 ft deep has formed through down-cutting in cross-section 2. This channel formation has also been observed through photographs and is discussed later. The profile comparison shown in Figure 6 shows that slight aggradation occurred at cross-section 4. Cross-section 4 is shown in Figure 9 and a maximum aggradation depth of 0.08 ft is observed.

Cross-section 3 is shown in Figure 10. The profile comparison shows down-cutting in this area, though the cross-sectional comparison shows aggradation. Figure 10 depicts a maximum depth of aggradation of 0.6 ft while Figure 6 shows only 0.09 ft of down-cutting. Compared to the scale of expected change and the possible error, the 0.09 ft is insignificant compared to the 0.6 ft of deposition observed in the cross-section. From these comparisons, it can be determined that both aggradation and down-cutting are occurring in the tributary to Big Walnut Creek. The cross-sectional comparisons in the upper portion of the site suggest that the inset channel formation observed in the pictures discussed below is caused predominantly by down-cutting and that aggradation is occurring in the downstream portion of the site.

From the cross-section comparisons, distinct channels were observed in two of them. In Figure 7 a 12 ft wide and 0.25 ft deep channel was observed. This creates a floodplain ratio of 2.9. It is also expected that this channel still deepens. From Figure 8 a channel 8 ft wide and 0.75 feet deep is observed. Both dimensions for this channel fall within the range predicted by the regional curve; suggesting that this might be the final stable geometry for this site. The width of 8 ft creates a floodplain ratio of 4.4.



Figure 6 - Big Walnut profile comparison



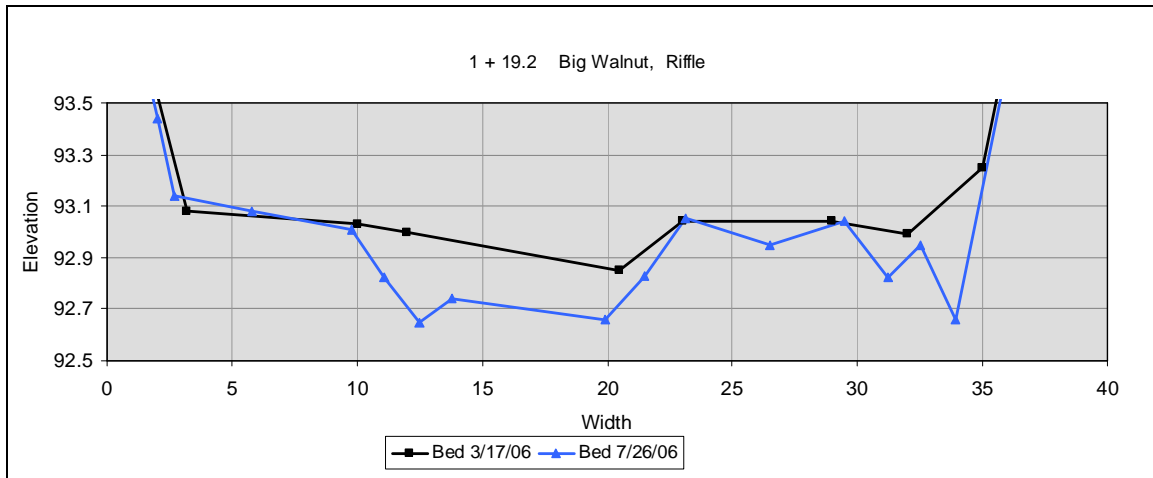


Figure 7 - Big Walnut cross-section 1

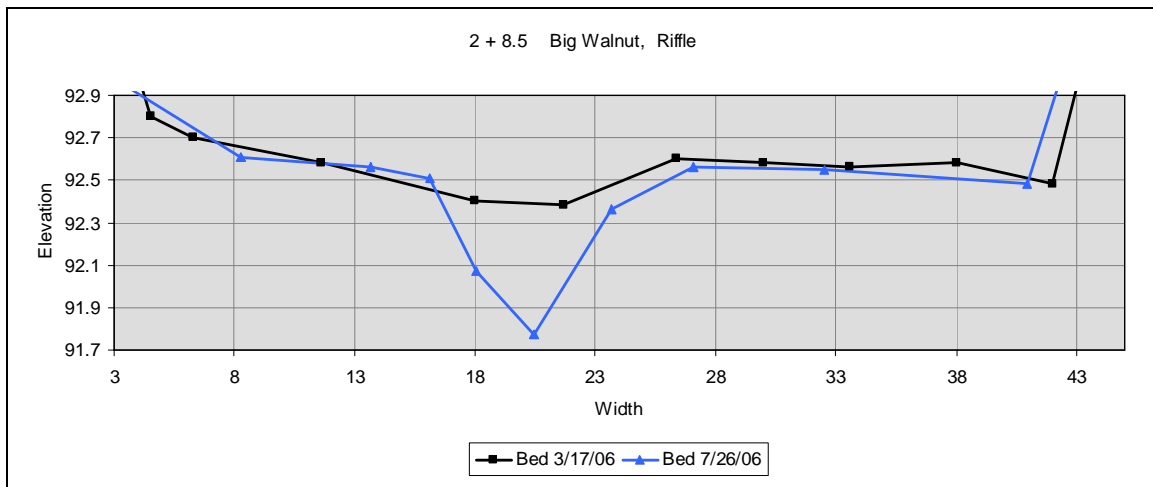


Figure 8 - Big Walnut cross-section 2

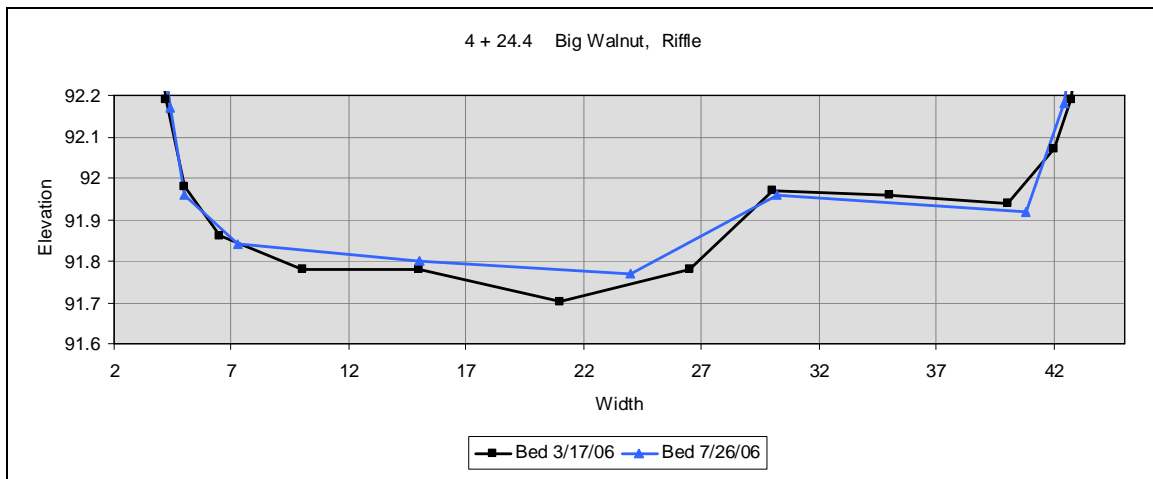
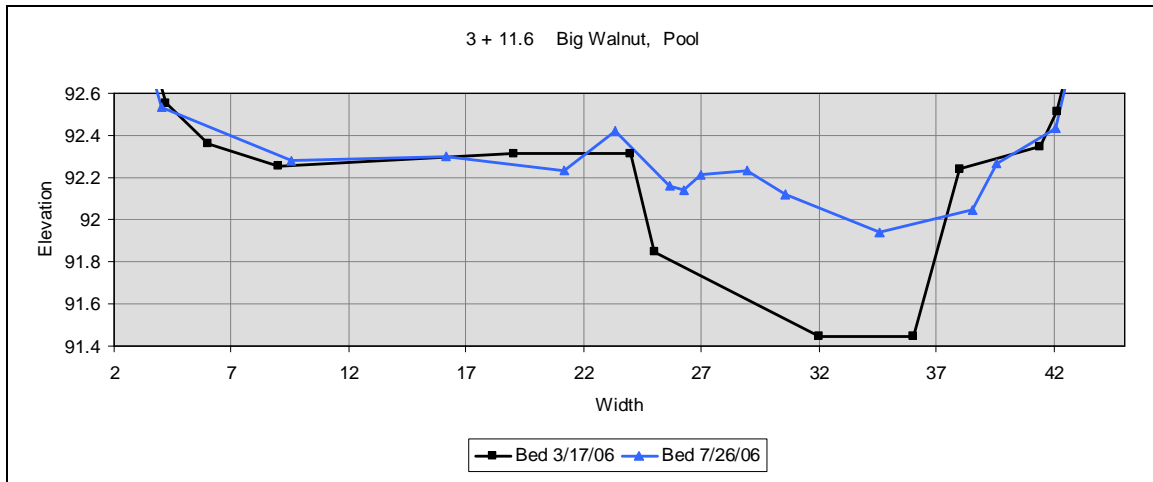


Figure 9 - Big Walnut cross-section 4





**Figure 10 - Big Walnut cross-section 3**

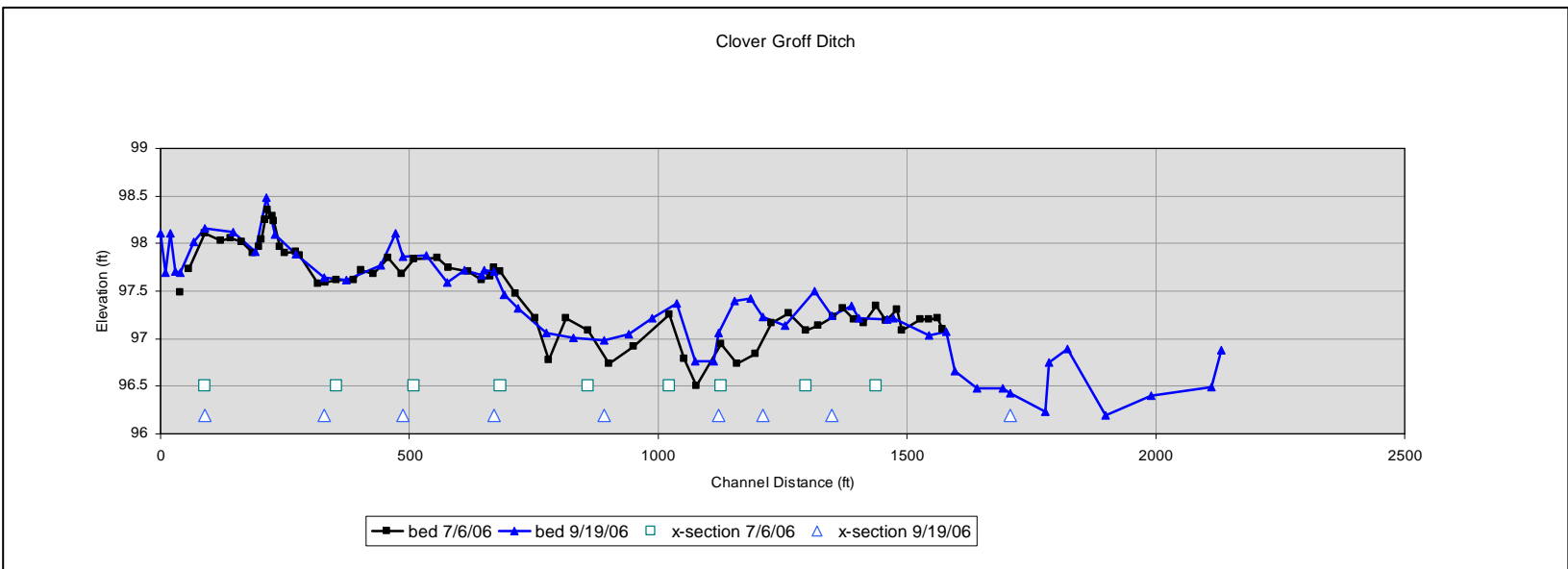
### *Clover Groff Run*

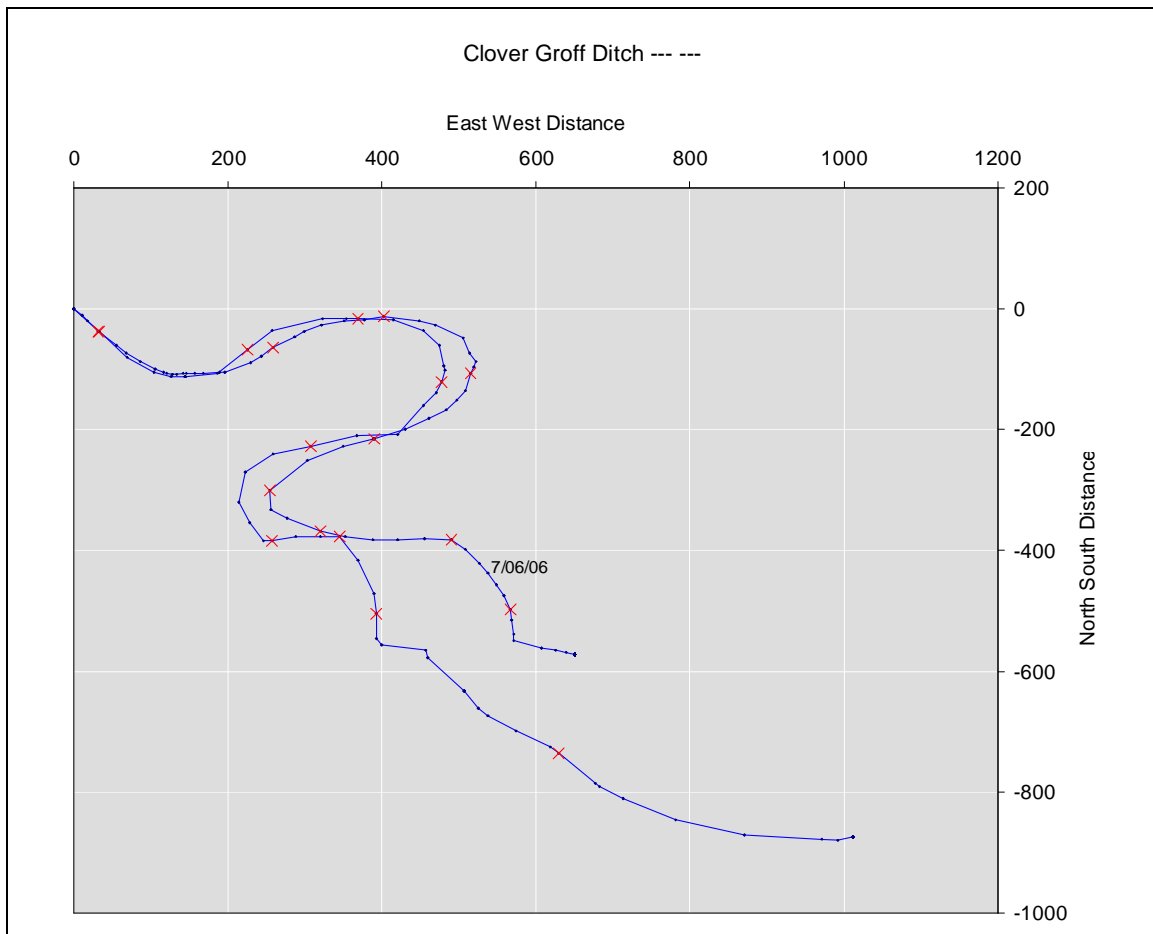
A similar physical comparison was performed for Clover Groff Run as is described above for the Big Walnut. The profile comparison is shown in Figure 11. The two profiles match closely for approximately the first 460 ft and then bounce back and forth. From this comparison alone, it appears that aggradation and down-cutting are occurring throughout the study reach. The research team recorded that the tread marks left by the excavating equipment created a rough channel bed. These ruts were generally several inches deep. Since the difference between the two profiles is generally only several inches, it is unclear whether this difference is caused by the choice for the profile points or aggradation/down-cutting. Besides the potential error caused by the equipment tracks, the average width of the over-wide channel is 95 ft and the entire width is generally wet. Though the surveyors attempted to measure channel length from the center of the over-wide channel, it is difficult to determine the center by eye for a 95 ft wide channel. Figure 12 shows that the measured channel pattern matches up closely for the third of the survey and then departs for the last third. These errors make the profile comparison inconclusive.

Though the cross-sections were originally marked with stakes and rebar, when the survey was reproduced in September several of the stakes were destroyed by a mower making it impossible to find the rebar among the dense vegetation. Though cross-sections were measured and remarked, they do not closely match up on either the measured profile or pattern and therefore were not compared for this study.

Despite inconclusive results from the actual surveys, researchers noted that they observed a layer of fine deposition throughout the site ranging from 0.25 to 1.0 inch. Soil scientists at ODNR DSWC suggested that this deposition most likely occurred during the construction of the over-wide channel itself.

Figure 11 - Clover Groff profile comparison





**Figure 12 - Clover Groff pattern comparison**

Unlike the Big Walnut study site, a narrow channel has not formed in the constructed over-wide channel at the Clover Groff study site. While aggradation and/or down-cutting may have occurred at this study site, the magnitude of bed elevation change is much smaller than the magnitude of the channel width and length making the results of the geomorphological survey comparisons inconclusive.

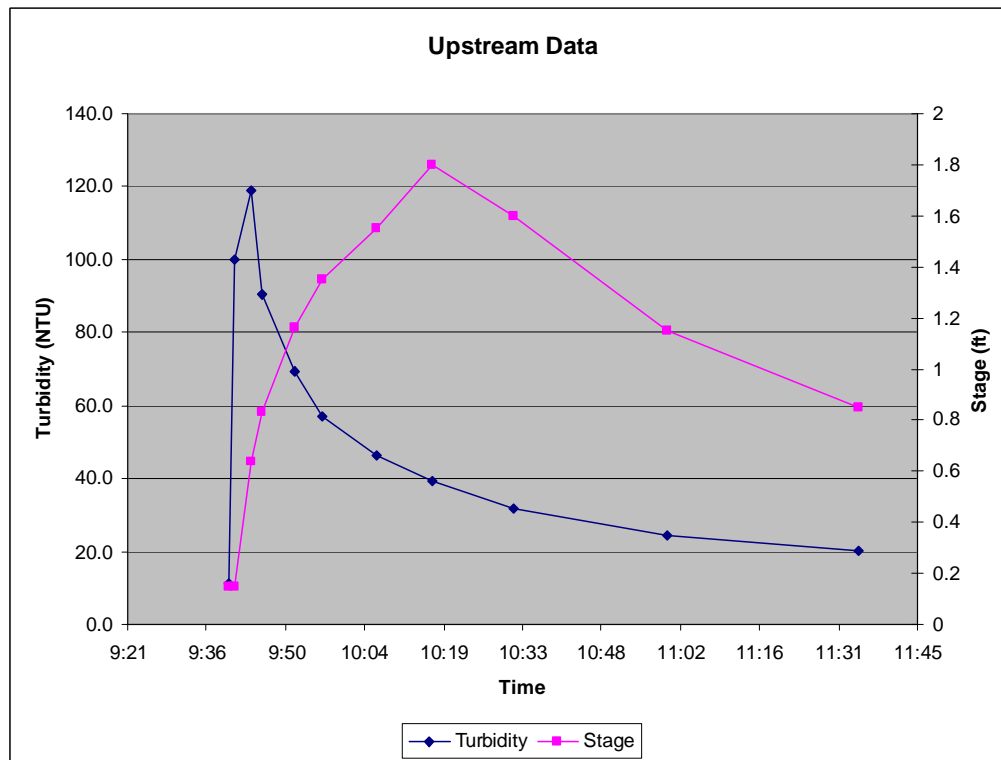
## **Turbidity**

### *Big Walnut Tributary*

Due to developer concerns, automatic samplers were not used on the Big Walnut study site. One storm event was captured through the use of grab samples. The data from the upstream researcher is shown in Figure 13. The upstream versus downstream turbidity is shown in Figure 14.

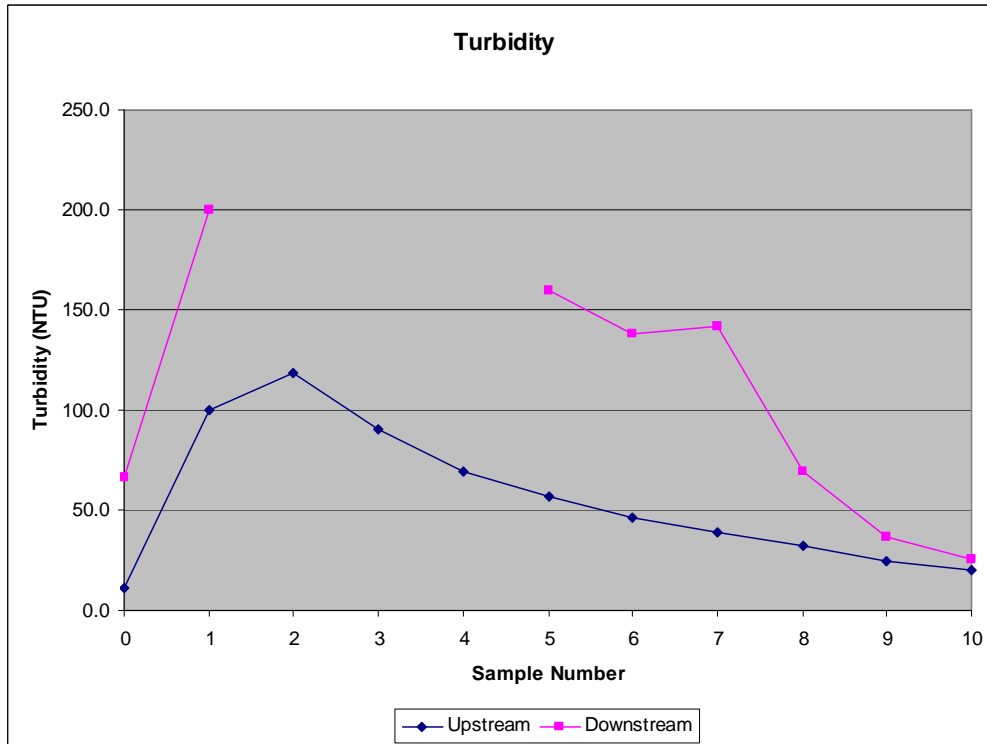
Assuming a similar relationship, Figure 13 shows that the peak pollutant concentration entering the study site does not occur at the peak of the hydrograph. This observation is consistent with the idea the first flush, or that the highest pollutant

concentration is carried within the first 20% of the runoff (Australian Environment Protection Authority and Sansalone, 2004).



**Figure 13 - Turbidity and stage data at upstream end of Big Walnut study site**

Figure 14 compares the upstream turbidity to the downstream turbidity. Eleven samples were taken (numbered 0 through 10). Samples 1, 2, 3, and 4 all had a turbidity of 200 NTU's, or higher; the maximum the turbidimeter could measure was 200 NTU's. Every downstream point had a higher turbidity than its corresponding upstream point. Using the same assumption as above, the downstream outflow would contain a higher concentration of suspended solids than the upstream inflow. This implies that sediment was picked up from the over-wide channel during this storm event and conveyed downstream.



**Figure 14 - Turbidity comparison between upstream and downstream for Big Walnut**

### *Clover Groff Run*

Two automatic ISCO samplers were placed at the Clover Groff study site and set to begin sampling when water was flowing at both the upstream and downstream sample site. Unfortunately, during the study period, no storm event occurred where water flowed from the upstream sampling site to the downstream site. Instead, a majority of flow entered the study site from a pond outlet approximately 500 ft downstream of the upstream sampler.

## **Photographs**

### *Big Walnut Tributary*

The series of photos examined for the study site on the tributary to Big Walnut Creek begins September 2005 and ends May 2007. During that time, obvious visual changes have occurred. Initially, the site was constructed as a wide, flat-bottomed trapezoid as shown in Photo 1. Two months later, the site was established with dense vegetation as shown in Photo 2 taken in November 2005. Also by this time, the flowing water had established a preferential flow path which can also be seen in Photo 2. This vegetation did not entirely survive the winter, though the preferential flow path did remain. This can be seen in Photo 3, a photograph taken June 2006. By August 2006, as shown in Photo 4, the higher areas seen in Photo 3 are covered densely with grasses and there is an obvious channel-floodplain system that has formed. During the winter of 2006-2007, grasses

stayed rooted on the floodplain and the channel-floodplain system was still clearly identifiable in January 2007 as shown in Photo 5. This defined channel is identifiable again during May 2007 as shown in Photo 6.

### *Clover Groff Run*

Unlike the study site on Big Walnut Creek, little physical change can be observed after construction on Clover Groff Run. Photo 7 shows Clover Groff Run just after construction in September 2005. The over-wide channel is wet across the entire width with little discernable difference in channel bed features. Photo 8 shows Clover Groff in November 2006. The channel is still wet across the entire width. Little change is visible between the November photograph and the May 2007 photograph shown in Photo 9. The only significant change is the dense vegetation growing on the edges of the channel. While a series of photographs may not help illustrate the changing physical features of the channel bed, they may help ecologists determine the succession pattern of vegetation at the study site.

## **Conclusion**

This study examined the physical changes of two study sites utilizing the over-wide channel design for stream relocation. The theory behind the over-wide channel design states that with a high enough sediment loading, floodplain benches will aggrade and form a bankfull channel. Through photographs and geomorphological surveys, it can be observed that a channel is forming at the Big Walnut study site. The size of the channel that is forming falls within the prediction of the regional curve analysis. Through examination of two surveys, it is observed that both aggradation and down-cutting are occurring at the study site. The turbidity analysis suggests that during certain storm events, the study site re-suspends or erodes producing suspended sediments. At the Clover Groff study site, channel formation has not been observed, though researchers did note a layer of deposition along the channel bed.

## **Future Studies**

This study has begun the process of determining how constructed over-wide channels develop after construction. To continue this database of information, the author recommends that future geomorphological surveys continue to be performed yearly at these study sites and at the other over-wide project sites. If possible, the utilization of a GPS based surveying system would allow researchers studying the larger over-wide sites to reproduce the surveys more easily. It would also allow for the recording of cross-sectional benchmarks with GPS coordinates.

At both study sites, it is recommended that more detailed water quality data be collected. Initially grab samples should be taken and analyzed in a lab for both turbidity and TSS. If a strong relationship is observed, then an electronic probe capable of

measuring turbidity in the field can be used instead of grab samples. Using a probe is not only cheaper, but allows the researcher to take more points than using grab samples. This relationship should be validated occasionally as both watersheds are rapidly changing. This will allow for the creation of a database that may help determine the quantity of pollutants that settle out in the over-wide channel; allowing over-wide channels to be evaluated using the current WQv standard.

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## Appendix A: Photographs



**Photo 1 - Big Walnut 09/01/2005**



**Photo 2 - Big Walnut 11/16/2005**



Photo 3 - Big Walnut 06/27/2006



Photo 4 - Big Walnut 08/28/2006





**Photo 5 - Big Walnut 01/03/2007**



**Photo 6 - Big Walnut 05/17/2007**





**Photo 7 - Clover Groff September 2005**



**Photo 8 - Clover Groff November 2006**



**Photo 9 - Clover Groff May 2007**